Smart home comfort and energy conservation using internet of things

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ABSTRACT

This new work presents a home automation system which employs internet of things (IoT) technology. This technology streamlines the design with an accurate home automation system which guides against the issues of energy wastage and excessive expenditure on the present systems of the utility company and the consumers. The system deploys a 32-bit ESP8266 system on chip (SoC) wireless fidelity (Wi-Fi) module which is linked to some sensors through a microcontroller for data communication. User friendly remote access, operation and management of the system are achieved through a mobile/web graphic user interface application. Daniel hall of students' residence at Covenant University is the location chosen for the deployment of prototype designed, the overall system achieved approximately 17% savings in energy consumption which in turn reduces the cost of energy usage for the same comform level.

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1. INTRODUCTION

Electricity, as a form of energy, has assumed a prime position as a major energy resource for mankind globally [1], [2]. An unrelenting increase in the human activities and desires have brought about continuous transcendence in the importance of electricity in most societies, even compared to other energy resources which are still in use such as charcoal and labour intensive efforts [3]. Electricity, which drives much if not most of the world's economic activity, is an important production factor [4]-[6]. But in a country like Nigeria, where the pace of population and industrial growth has fast outgrown the population maintenance capability of the government, the demand for electricity has become a farfetched task for supply [7], [8]. Apart from the fact that total generated electric power in the country is not able to meet up with population demands, there has also been the issue of poor maintenance of energy [9]. From an analytical study, the approximate sum total of generation capacity, according to [10], is 5,000 MW to serve total population of 191,835,936 [11]. Hence, using (1):

$$Capacity = \frac{Total\ Generated\ Capacity}{Total\ Population} \tag{1}$$

Which leads to

$$Average\ Generated\ Capacity = 26.064\ W/head.$$

Looking at this analysis, it is observed that evenly distributed power supply to every inhabitant will be at 26.064 W, which is just enough to power up a highly efficient light bulb (for example, light emitting diode (LED) bulb, or compact fluorescent lamp (CFL)). The analysis above has not even considered the influence of the process driven and manufacturing industries and energy loss due to theft stated in [12]. An average home requires at least 6.5 kVA of power supply to support domestic living including lighting, refrigerator, water pump, television (TV), and fan basically [13]. This is why some parts of the country are left in total darkness while those who have access to the grid do not even experience adequate sustained electric power [7], [14], [15].

Although, the best solution would be to increase the number of generation plants in different regions and to improve the transmission capacity, these approaches are very expensive and time demanding. It will result in a long-time blackout during the system upgrade period. An efficient solution is to deploy an energy conservation technique at utility side [16] which is proposed in this study.

Utility energy conservation involves two major aspects: the optimal use of electrical appliances and the use of energy efficient appliances. The optimum use of electrical energy can be implemented in various forms including manual control of electrical appliances, remote control of electrical appliances, automated operation of appliances based on human presence, or automated operation of appliances based on time duration (or real-time inclusively). These forms of energy conservation techniques are referred to as demand-side management (DSM), this is because the activities involved and the manner of operation are handled by the consumers [17].

Several works, with various approaches, have been carried out for the purpose of realizing the feasible deployment of the smart home and improving on some of its gaps and capabilities. In a smart home project carried out by [18], the main focus of the intended energy management system (EMS) was on real-time pricing (RTP). Several network modules were implemented for load data collection, task implementation, feedback, and information generation between the consumers and suppliers, enabling a robust and flexible system that can modify and adjust the operation settings of each load. One of the benefits of this study is that, unlike the usual fixed priced electricity supply, residential RTP customers are charged for the electricity they consume each hour based on the corresponding wholesale hourly market price of electricity. The pricing flexibility also takes into account the load operations during peak hour, posing a cheaper price rate for load saving programmes as the EMS monitors the consumers' activities [13]. The data acquired from the monitored consumer activities is used to generate an algorithm to predict near future activities that the power authority can work with to maintain the consumer comfort level for situations such as scheduled outages. Zhao *et al.* [18], three different modes, with built-in settings to navigate the EMS between comfort and energy conservation, were considered. These are comfortable, smart and savings modes. The comfortable mode placed consumer comfort as top priority irrespective of hourly pricing or peak period. The smart mode sets up a program to create an even balance between the consumer's comfort level and hourly pricing. The savings mode ignores the comfort level of the consumer to ensure a significant amount of conserved energy. In the design proposed by Cui *et al*. [19], the EMS was merged with cloud technology to reduce the stress on the control unit of the system due to increasing functionalities. Numerous data and increase in the complexity of control bring about heavy burden on the local computer storage and processors. The cloud technology helps to store all the monitoring data, processing data, data logs for consumption and all other data required for the automated control of the appliances in the building. The proposed smart home design was built with an expanding scope of application in view because it is expected for more or newly improved electrical/electronic appliances to be installed in the building. So, therefore, in order to adapt to changing load without having to remodel the power system of the building, a system with a powerful computing capability and storage capacity is required, and this is where cloud computing technology is implemented. The results from this experiment show that a smart home on the cloud platform is more convenient, flexible, highly efficient, and has low cost. Even with the benefits obtainable from the cloud platform, there are also some downsides to it. These include constant or dedicated (depending on the smart home structure) internet connection, which poses as an additional energy consumption to the system, and also the additional cost of subscription to the internet and the cloud platform. There may also be times where there will be loss of internet connectivity. This means there will be no link between the devices and the control system (which is on the cloud). For example, in a real life scenario when a glitch suddenly occurred on Amazon Web Services, it caused both websites and smart homes on their platform to experience a three-hour blackout [20], [21]. It can therefore be seen that as beneficial as a cloud based smart home can be, the smart home should not just solely or completely rely on the cloud, but a local storage and processing system should also be in place to prevent such situation from occurring in the future. The only issue with such a situation will be that the local storage and processing system will not contain all the information and functions as the cloud can handle.

In this present work, energy management techniques are employed to achieve high energy conservation. Practical application of this technological energy management techniques i.e. automation and

remote control of appliances in a habitation, is referred to as a smart home energy management system (SHEMS) [22]. The aim of this present work is to develop an electrical system that automatically controls the working operation of electrical appliances within a house to maintain comfort, minimize the level of energy consumption and to save cost over a period time. This work combines both cloud technology and offline to achieve efficient energy management technique without any down time for user comfort which is absent in [16].

2. Materials and methods

The smart home energy management system (SHEMS) is a control system that coordinates the working operation of the power system in the home. The basic requirements for the realization of a modern smart home are power supply that provides power for the control system, a programmed/programmable controller that determines the working operation of the electrical loads, a load interface that connects the output load to the control system, and component/subsystem intercommunication. The proposed SHEMS discussed in this work goes beyond this basic description for the purpose of a wireless telecontrol and telemonitoring over the internet.

2.1. The power supply

The power required is supplied from the main power distribution in the house and it is divided into two for loads and control system. This is because both the loads and the system controlling the loads have different voltage types and magnitude requirements. The loads are powered directly from the 220 V ac distribution board (DB), while the control system is powered from a 12 V dc source. Two other dc voltages are tapped with voltage regulator from the 12 V dc. These are 5 V and 3.3 V for real-time clock sensor and Wi-Fi module respectively.

2.2. The microcontroller

The microcontroller is the backbone of the entire management system because it is the component that coordinates all the activities of the entire system. It acts as the brain centre of the system because all other major components (sub-systems) are directly connected to it. The microcontroller proposed in this work is the AT-Mega328p microcontroller unit (MCU). It consists of 28 pins, each with its unique purpose. Except for the ground pins that have a constant of 0 V, all other pins work within the range of 0 V to 5 V. Many of these pins are multiplexed to perform additional functions which include various communication interfaces, serial interfaces, pulse width modulation (PWM) outputs and external interrupts. A 16 MHz ceramic resonator is wired to its clock pins, serving as the reference by which all program commands execute [23].

2.3. RTC

A real-time clock (RTC) is an integrated circuit built maily for time record. It basically counts hours, minutes, seconds, months, days and even years. RTCs are present in computers, embedded systems and servers. They are able function even when the computer is shout down through a battery. DS1307 RTC chip is proposed in this work to control operation based on real time as set in the microcontroller i.e. it determines the time of the day/night when a particular operation is triggered [24].

2.4. Read-in devices

The read-in devices are the electronic components from which the microcontroller gets the desired externally generated parameters [25]. They can be connected to data pin(s) of the microcontroller including digital, analogue and PWM pins, depending on the nature of data generated by the read-in device. The read-in devices proposed in this work are the passive infrared (PIR) motion sensor, light dependent resistor (LDR), humidity and temperature sensor (DHT11), and RTC.

2.4.1. PIR sensor

The PIR sensor is a motion detector that switches between low and high states based on the range of wavelength of radiation which it senses. It switches high when it senses a radiation with wavelength between 8 μm and 14 μm. The sensor has three pins: VCC (i.e. collector-collector voltage) pin for a 5 V dc power supply, output pin to send a digital signal (low or high) to the microcontroller and the ground (GND) pin that completes the circuit to ground. When it switches high, it causes the corresponding output pin of the microcontroller to switch high, sending a 5 V signal to trigger the main load interface, so that all other load interfaces can be powered on standby.

2.4.2. LDR

It is an optoelectronic resistor whose resistance is inversely proportional to the light intensity on it and generates a nonlinear output voltage under the influence of light. In total darkness, the LDR attains maximum resistance even up to about 1 MΩ, which reduces at the instance of light incidence. The digital

representation of the resistance range of the LDR runs from 0 to 1023, that is, mathematically written as $0 \leqslant R < 1024$, due to the 10-bit resolution of the analog to digital converter (ADC) of the Arduino Uno [23]. In this work, the LDR is deployed for the following two main purposes:

- To switch on the power supply into the given apartment on the entry of a person, and to switch it off on the exit of all the occupants.
- To switch on the room lighting based on the ambient luminosity in the room. This is a technique commonly known as daylight energy saving.

2.4.3. Temperature and humidity sensor

DHT11 is the proposed temperature/humidity sensor model in this work. It is a digital output device that monitors both the temperature and relative humidity level of a room in the house. It has three connection pins: voltage common collector (VCC) pin for power supply, data pin to transmit signals collected from both the temperature and humidity values to the microcontroller and the GND pin that completes the circuit to ground. For this work, the threshold temperature is 27 ºC, and the threshold relative humidity is 47 because these are the average, appropriate temperature and humidity levels for humans indoors (average, appropriate, indoor weather condition). Thus, when the temperature in the living room or bedroom is below 27 ºC, the corresponding ventilation fans re-main off, keeping energy conserved since they are not required at that point in time. Similarly, when the humidity level of the kitchen or bathroom is below 47, the exhaust fans stay off until there is an activity in these rooms that will cause the relative humidity level to shoot up to the required level. The DHT11 should be placed at a strategic position where the breeze from the fans will not affect the environmental conditions of the sensors drastically as to cause undesirable fluctuations in their operations.

For this study, two laser receptive, light-dependent resistors (LDRs) are placed at the entrance for determining entry and exit, and occupancy count. A large surface LDR is placed near the window as a dark sensor to measure ambient brightness to determine the powering of the light based on the darkness level in the room. A DHT11 is used to control the operation of an air extractor and a ventilation fan respectively to maintain good atmospheric condition in the room. A PIR motion sensor is used to momentarily switch on the passage light, since the passage light is only required when at least a person is passing through. One relay is connected to an individual appliance, except for appliances that are required to operate based on the same control parameters. The contactor (represented by a much higher capacity relay) is simultaneously connected to all the other relays so that power does not get to them until entry is detected as shown in Figure 1.

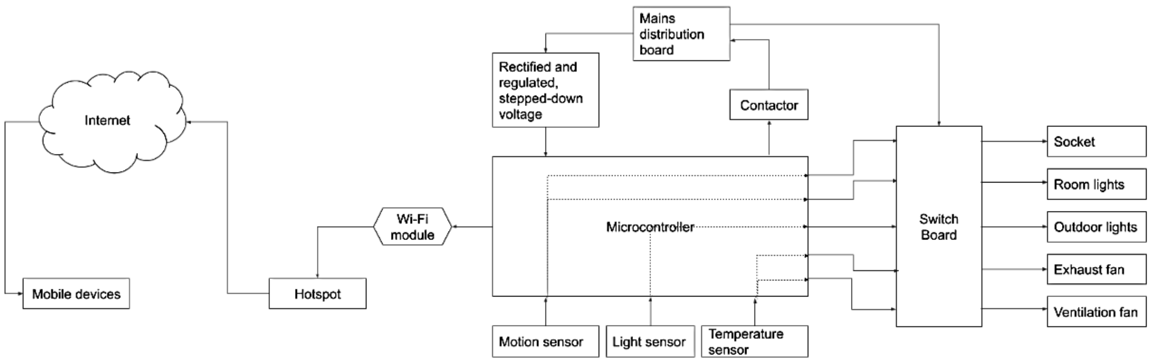

Figure 1. Smart home energy management system model

2.5. Circuit design

The circuit designed as shown in Figure 2 is the circuit simulation, it was simulated to ensure that the required components for an ideally working system is derived. The simulation program was run with the Proteus 8 application for the Windows operating system, with the inclusion of the Arduino library and sensor libraries. With these libraries, the programme codes were compiled and imported to the Proteus through the Arduino library. All the simulations worked perfectly well in line with ideal situations.

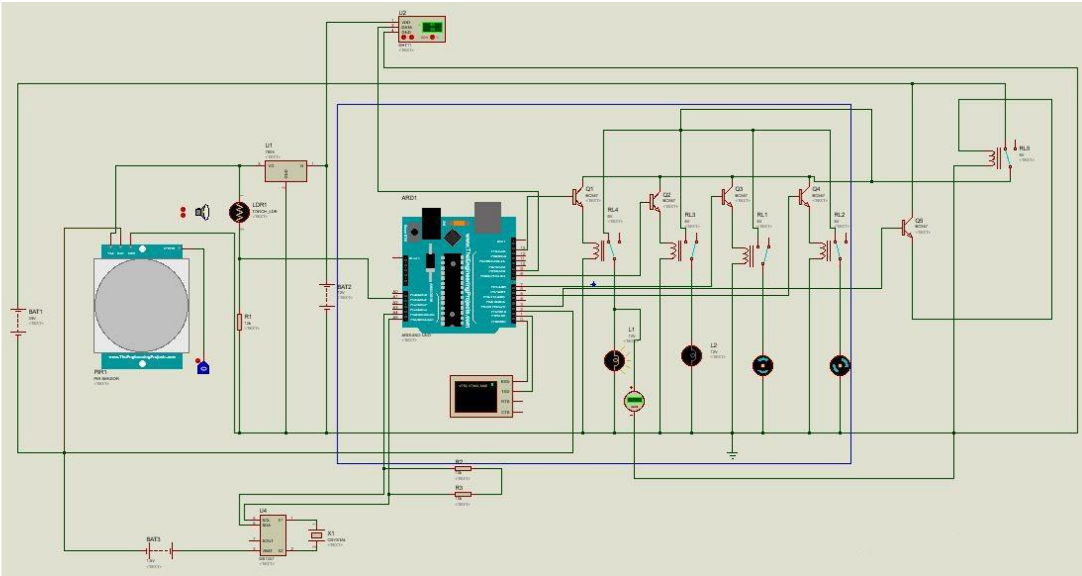

Figure 2. Circuit simulation

Prototyping (i.e. testing) was carried out after every significant change in the circuit design from the simulation until a very much desirable result was achieved. The prototyping was carried out in an unconducive environment with poor lighting in a room that was hot and closed up, after which the conditions were varied by opening the curtains and windows. The fans and lights were also switched on to ensure the workability of the circuit. This also involved changing some of the codes in the written programme, most especially the variables of the sensors, in order to derive a desirable and standard baseline (threshold) for the conducive conditions of the room.

The software used in this study, Cayenne is a graphic user interface (GUI) and internet of things (IoT) platform made by myDevices for the personal computer (PC) web browsers, Android and iOS devices. It is a drag and drop project builder with important features such as database, cloud and application, with offline view capability. The readings from each sensor are displayed as a graph, gauge or digital meter as shown in Figure 3. It also consists of trigger and event functions that determine the automatic operation of the controlled appliances based on the threshold readings set on the sensors pertaining to those appliances. Each sensor and relay are placed in the database of the cloud with a unique identity and defined function, from which data is collected via the sensors, and appliances are controlled via actuators (relays). When the application comes up, it appears as a dashboard made up of all the components that have been defined on it, each represented by the given ID icon and name. The dashboard, including the switch icons for the lights, fans, socket outlets and mains, is shown in Figure 3.

The graphical monitor for the darkness sensor, entrance detector, exit detector, the digital indicator of humidity, and the humidity gauge are also contained on this dashboard. There are also graphical sheets for temperature and the darkness sensor for a better imaginative understanding of those environmental factors and how they affect the energy sufficiency control. The presence of the IoT platform and internet connectivity via the ESP8266 (ESP-01) Wi-Fi module allows for the override control of the actuators irrespective of the sensor input. This is made possible because of the inverted condition within the Cayenne function in the integrated development environment (IDE) of the Arduino.

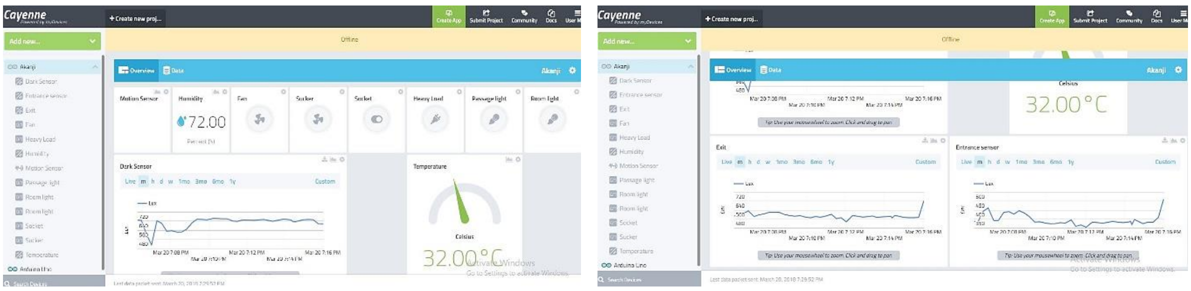

Figure 3. Cayenne IoT dashboard

3. RESULTS AND DISCUSSION

The physical implementation and testing of this system were carried out on the second floor of the entrance of the Daniel hall of students' residence, Covenant University (latitude: 6.692745, longitude: 3.236485, altitude: 69 meters). That is, (6°40'17.4"N 3°09'08.8"E 69m), for the purpose of consistency and minimization of errors while the test was being carried out, standard was set for each of the environmental parameters. The following subsections 3.1 to 3.5 discuss the result obtained from different components.

3.1. Motion

The HC-SR501 PIR motion sensor has a maximum detection range of 6 m at minimum sensitivity. This has no problem concerning the test environment which has a volumetric dimension of 4 m × 3 m × 3 m. The other motion sensing system in this work is the dual line break detector consisting of two pairs of light emitting diodes (LEDs), lasers and LDRs, with each LDR paired up to face one laser directly. If the laser LDR line, which is closer to the door gets broken before the one ahead of it, then the control system will indicate entrance and vice versa.

3.2. Temperature

The average temperature for the week were 33 °C during the day and 24 °C at midnight/dawn respectively as shown by the Google Weather forecast in Figure 4 which provides a thermometer feature to be used for this work at the considered location by the global positioning system (GPS) embedded in our computer system. The threshold temperature for the control of the fan was set for 27 °C. This means that if the temperature of room goes above 27 °C, the fan automatically comes on as long as there is power supply in the room provided by the entrance function of the system. But once the temperature of the room goes below that threshold, the fan goes off and stays off until the temperature goes above the threshold again.

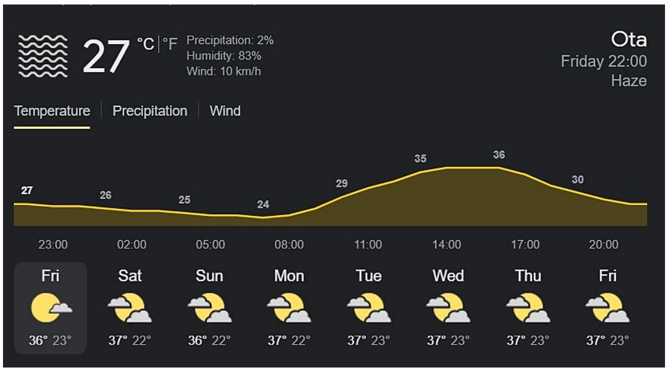

Figure 4. Weather forecast

3.3. Humidity

This is determined by the relative humidity (RH) and not the absolute humidity. The minimum RH ever recorded from the various calibration tests of the DHT11 humidity sensor has been 78%. Many at times, it has gone up to 84%, which is just about 8% less than the maximum permissible indoor RH level of 92%. There are the two parameters to be considered in setting the RH threshold. These are;

- comfort: for the purpose of comfort, the threshold is set to 50%, since it is closer to the average determined RH level for most people, 46.2% [26]; and
- electrical energy conservation: in order to minimize energy cost, the threshold is set for 80%, which is the average of the maximum and minimum RH values experienced in this environment where the test is being carried out. This is the default setting chosen for this project.

3.4. Real-time clock (RTC)

The RTC makes use of a laptop time from which it was referenced. The 3.3 V coin battery on the RTC keeps the RTC time active; else, without it, it will get reset. The RTC switches the power to the socket labelled off between the hours of 9 am and 5 pm from Monday to Friday, which is the usual time when power is supplied to the hall of residence on weekdays.

3.5. Internet control

The internet control makes use of the control widgets set on the dashboard to control all the corresponding appliances such as the lights, dc motors and sockets. Each widget was tested to confirm proper

working condition. Table 1 shows the energy consumption without energy control system while Table 2 shows the energy consumption under control system.

In the Table 1 and Table 2, it is clear that a significant amount of energy (i.e. 17%), was saved when the energy management system (EMS) was implemented. A large chunk of this savings is the lightbulb 2 (passage light), which represents the light leading to the bathroom that is usually left on throughout the night. But with the EMS, the light comes up only when an individual is going through the passage. It can also be seen that the power consumption from the power outlets did not change. This is because, the regulation of the power outlets is consistent with the use of these appliances. Also, more energy was saved during the sunny days than in the cloudy days. This result will be quite beneficial for most parts of Nigeria, most especially in the northern part, which is the largest in terms of population and land size. The result is also beneficial for the tropical region since on the average, the rainy season is quite shorter than both the dry season and the August break, with a ratio of five to seven (5:7) in terms of the total number of months in a year.

With the apartment considered for SHEMS, the scenario for this system is to power up the house only if a person has entered into a particular room provided that power supply is available, allowing power supply to the socket outlets irrespective of the environmental conditions. Based on the level of natural brightness in the room, the room lights switch on when the natural light is below the set threshold for good human vision. The temperature and humidity sensors control the switching of the air extractors and fans respectively, based on the recent humidity and temperature within the room with respect to the threshold values set on the microcontroller.

For peak load shifting, a digital real time clock device, DS1302, was used to monitor specific hours of the day when that particular geographic location experiences peak load, in order to determine when certain loads should be switched off to avoid total power outages. This allows the consumers to have access to basic utilities such as lighting, fan, charging and powering small devices like laptops and mobile phone, for example. For this, a dedicated set of powering outlets is used for such electrical appliances. This real time function can also be performed by the trigger and event features of the Cayenne application.

Table 1. Energy consumed without energy control system

Appliances	Power rating (W)	Power-on duration in 24hrs (h)	Energy consumed (Wh)
Lightbulb 1	60	10	600
Lightbulb 2	60	11	840
Ceiling fan model	2.4	14	33.6
Air extractor	1.8	14	25.2
Socket 1	372 (336, 36)	(6, 3)	2,124
Socket 2	2,100 (1100, 1000)	(2, 0.1)	2,300
Total	2,596.2		5,922.8

Table 2. Energy consumed with energy control system

Appliances	Power rating (W)	Power-on duration in 24hrs (h)	Energy consumed (Wh)
Lightbulb 1	60	7	420
Lightbulb 2	60	0.5	30
Ceiling fan model	2.4	12	28.8
Air extractor	1.8	14	25.2
Socket 1	372 (336, 36)	(6, 3)	2,124
Socket 2	2100 (1100, 1000)	(2, 0.1)	2,300
Total	2,596.2		4,928
			994.8
Saved			
% savings			16.796%

4. CONCLUSION

The purpose of this research is in threefolds: i) to regulate the electrical energy consumption; ii) to discourage energy wastage; and iii) to maximize the use available energy, while maintaining consumer comfort. This was achieved by applying restrictions to the power outlets in the power system of the house. The specific restrictions imposed were made possible by the use of sensors, each designed to monitor a particular function such as motion, direction, ambient illumination, ambient temperature, and relative humidity. A real time clock is also included to set the time for specific actions. And lastly, internet control was applied to the system via the use of the Cayenne IoT platform and an ESP-01 Wi-Fi module. In this work, a new approach different from previous once was deployed to achieve demand side energy management scheme which does not compromise the comfort of the users. The reduction in energy waste and cost of energy usage comfort is quite impressive and can further be improved upon as innovation continues to evolve.

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